U.S. PATENT APPLICATION

for

METHOD FOR DETERMINING THE AMOUNT OF CHARGE
WHICH CAN BE DRAWN ON A STORAGE BATTERY, AND
MONITORING DEVICE FOR A STORAGE BATTERY

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METHOD FOR DETERMINING THE AMOUNT OF CHARGE WHICH CAN BE DRAWN ON A STORAGE BATTERY, AND MONITORING DEVICE FOR A STORAGE BATTERY

CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

[0001]　Germany Priority Application DE 102 40 329.5-34, filed August 31, 2002 including the specification, drawings, claims and abstract, is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002]　The invention relates to a method for determining the amount of charge which can be drawn from a storage battery. The invention also relates to a monitoring device for a storage battery having measurement means for measurement of battery voltages and battery currents, and also having evaluation means.

[0003]　It may be desirable to estimate the amount of charge which can be drawn from a storage battery during operation.

[0004]　U.S. Patent No. 5,761,072 describes a method for determining the capacity of a storage battery for this purpose, in which a filter is used to determine a fast current and a slow current is determined by averaging by means of integration. The values for the fast and slow current are entered in what is referred to as a Peukert relationship in order to determine a capacity for a fast current and for a slow current. These capacities are weighted, and are used to calculate a total capacity.

[0005]   DE 694 23 918 T2 describes an apparatus for indicating the extent to which a battery is empty, in which measurement values of, for example, the no-load voltage or internal impedance are recorded periodically. These measurement values are filtered via a low-pass filter, and their mean value is determined. If the mean value exceeds a threshold value, an empty warning indication is produced.

[0006]   DE 691 31 276 T2 discloses an electronic tester for assessing the percentage energy capacity of a battery or of a battery cell. In this method, the dynamic conductance is determined and is compared to a reference conductance, which corresponds to the dynamic conductance of a battery or battery cell with a 100 percent capacity.

[0007]   These previously known methods and apparatuses may be used to determine the state of charge of a new battery. However, such methods may be desirable for determining the amount of charge which can still be drawn from a used battery, particularly at low current levels.

[0008]   One difficulty is that the amount of charge which can be drawn from a fully charged storage battery can decrease for various reasons (i.e., it may no longer be possible to draw the same amount of charge from a used storage battery as for a battery in a new state). These reasons may, for example in the case of lead-acid rechargeable batteries, be the loss of active material due to precipitant formation, sulfatation, or the like.

[0009]   If, by way of example, the state of charge of a storage battery is determined by measuring the no-load voltage, as is possible for example in the case of a lead-acid rechargeable battery, then it is not possible to use this value to make any statement about the amount of charge Q_R which can still be drawn from the fully charged storage battery when it is

no longer new. The reason for this is that, although the state of charge is a measure of the amount of charge which can be drawn from the acid in this case, the amount of charge which can still be drawn from the active material is not correlated with the amount of charge in the acid when new.

[0010] If the state of charge (SOC) is defined as the quotient of the difference between the nominal amount of charge and the amount of charge drawn with respect to the nominal amount of charge,

$$SOC = \frac{\text{Nominal amount of charge - Amount of charge drawn}}{\text{Nominal amount of charge}}$$

then the state of charge (SOC) likewise does not provide any information about the amount of charge Q_R which can be drawn.

[0011] Based on this definition, the state of charge provides no information about the actual amount of charge Q_R which can be drawn from a used storage battery.

[0012] U.S. Patent No. 5,721,688 and U.S. Patent No. 5,572,136 disclose apparatuses and methods in which a relatively small current which varies with time is applied to a storage battery, and the time-dependent voltage response of the storage battery is observed and evaluated. The conductivity of the storage battery can be determined from the voltage response. However, during operation, it is not always desirable or possible to apply a separate measurement current.

[0013] There is thus a need for an improved method for determining the amount of charge Q_R which can be drawn from a storage battery in the fully charged state. There is also a need for a monitoring device for a storage battery, by means of which it is possible to determine as

accurately as possible the amount of charge Q_R which can be drawn from a used storage battery, using relatively simple means.

SUMMARY OF THE INVENTION

[0014]   An exemplary embodiment relates to a method for determining the amount of charge which can be drawn from a storage battery. The method includes determining a battery voltage profile and a battery current profile over at least one time interval and smoothing the battery voltage profile and the battery current profile using at least two different smoothing measures. The method also includes determining voltage differences between the battery voltage profile smoothed using a second smoothing measure and the battery voltage profile smoothed using a third smoothing measure, with the third smoothing measure producing greater smoothing than the second smoothing measure. The method further includes determining the current differences between the battery current profile smoothed using a second smoothing measure and the battery current profile smoothed using a third smoothing measure, with the third smoothing measure producing greater smoothing than the second smoothing measure. The method further includes calculating characteristic values from quotients of the voltage differences and the current differences, utilizing the characteristic values for a time interval to determine an interval characteristic value, and determining of the amount of charge which can be drawn from the storage battery from at least one interval characteristic value for at least one time interval.

[0015]   Another exemplary embodiment relates to a monitoring device for a storage battery. The monitoring device includes a measurement component for measuring battery voltages and battery currents and an evaluation component. The evaluation component designed to carry out a

method that includes determining a battery voltage profile and a battery current profile over at least one time interval and smoothing the battery voltage profile and the battery current profile using at least two different smoothing measures. The method also includes determining voltage differences between the battery voltage profile smoothed using a second smoothing measure and the battery voltage profile smoothed using a third smoothing measure, with the third smoothing measure producing greater smoothing than the second smoothing measure. The method further includes determining the current differences between the battery current profile smoothed using a second smoothing measure and the battery current profile smoothed using a third smoothing measure, with the third smoothing measure producing greater smoothing than the second smoothing measure. The method further includes calculating characteristic values from quotients of the voltage differences and the current differences, utilizing the characteristic values for a time interval to determine an interval characteristic value, and determining of the amount of charge which can be drawn from the storage battery from at least one interval characteristic value for at least one time interval.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016]   The invention will be explained in more detail in the following text using the attached drawings, in which:

[0017]   FIGURE 1 shows a diagram of battery current profiles which are filtered using different time constants and which shows defined limit values;

[0018]   FIGURE 2 shows a flowchart of a method according to an exemplary embodiment for determining the amount of charge which can be drawn; and

[0019]   FIGURE 3 shows a diagram of the amount of charge which can be drawn plotted against the interval characteristic value for two different temperatures.

DETAILED DESCRIPTION OF THE PREFERRED
AND EXEMPLARY EMBODIMENTS

[0020]   According to an exemplary embodiment of the present invention, a method for determining the amount of charge which can be drawn from a storage battery includes determining a battery voltage profile and a battery current profile over at least one time interval; smoothing the battery voltage profile $U(t)$ and the battery current profile $I(t)$ using at least two different smoothing measures; and determining the voltage differences $\Delta U_{23}(t)$ between the battery voltages smoothed using a second smoothing measure and the battery voltages smoothed using a third smoothing measure, with the third smoothing measuring producing greater smoothing than the second smoothing measure. The method also includes determining the current differences $\Delta I_{23}(t)$ between the battery currents smoothed using a second smoothing measure and the battery currents smoothed using a third smoothing measure, with the third smoothing measure producing greater smoothing than the second smoothing measure. The method further includes calculating characteristic values from quotients of the voltage differences and from the current differences, utilizing the characteristic values for a time interval to determine an interval characteristic value, and determining the amount of charge which can be drawn from the storage battery from at least one interval characteristic value for at least one time interval.

[0021]   It has been found that a relatively simple evaluation by determination or calculation of measured battery voltages and battery

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currents (e.g., generation of battery voltage or current profiles) of a storage battery during operation can be used to determine the amount of charge which can be drawn. This is achieved by suitably smoothing the battery voltages and battery currents to produce a reference voltage and a reference current by choosing a long time constant as the smoothing measure, using which the difference from the battery current and battery voltage smoothed using a shorter time constant can be assessed. This can be done by continuously measuring and evaluating by calculation the battery voltage and battery currents over at least one time interval.

[0022] The smoothing is preferably carried out by filtering using time constants, by averaging, in particular with a sliding average or the like.

[0023] The calculated characteristic values are preferably used to calculate a mean value as the interval characteristic value. The mean value may also be a sliding average or median, etc.

[0024] It is advantageous for the characteristic values to be calculated or to be used to determine the interval characteristic value only when certain conditions are satisfied. The amount of charge which can be drawn is thus determined only on the basis of permissible characteristic values.

[0025] One condition may be for the magnitude of current difference $\Delta I_{23}(t)$ to be less than a defined second limit value. Alternatively or additionally to this, a further condition may be that the magnitude of the current difference $\Delta I_{12}(t)$ of the battery current smoothed using the second smoothing measure and the battery current smoothed using a first smoothing measure is less than a defined first limit value, with the first smoothing measure producing greater smoothing than the second smoothing measure.

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[0026]   As a further condition, it is possible to provide for the battery currents smoothed using the second smoothing measure to be greater than a third limit value and less than a fourth limit value.

[0027]   It is also possible to stipulate that the magnitude of the current difference $\Delta I_{23}(t)$ is greater than a defined fifth limit value and/or the magnitude of the current difference $\Delta I_{12}(t)$ of the battery current filtered using the second time constant and of the battery current filtered using a first time constant is greater than a defined sixth limit value.

[0028]   The first and the second limit values are preferably in the region of the 30-hour to 80-hour current of the battery, and preferably correspond approximately to the 50-hour current. The third limit value preferably corresponds approximately to the 10-hour current and the fourth limit value corresponds approximately to the 30-hour current, with a tolerance of approximately 50% still leading to comparable results.

[0029]   For lead-acid rechargeable batteries of approximately 70 ampere hours (Ah), it has been found to be advantageous to use a first limit value in the region of approximately 1 ampere (A), a second limit value in the region of approximately 1 A, a third limit value of approximately -5 A, and a fourth limit value in the region of approximately -2 A. The limit values should be regarded only as approximate guidelines, since the method depends on the type and size of the battery.

[0030]   It is particularly advantageous for the permissible characteristic values which satisfy the conditions mentioned above to be integrated in one time interval. The times in which permissible characteristic values are present are likewise integrated, in order to calculate the time duration of the time interval. The interval characteristic value is then calculated as the quotient of the integrated characteristic value in the time interval, as

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calculated by integration of the permissible characteristic values, and the time duration of the time interval.

[0031]   The interval characteristic values are preferably weighted as a function of the state of operation of the storage battery. By way of example, the weighting factors used while the storage battery is being discharged are not the same as those used when it is being charged.

[0032]   It has been found to be advantageous for the amount of charge which can be drawn to be determined from the at least one interval characteristic value as a function of the state of charge of the storage battery and of the battery temperature, for example with the aid of families of characteristics which are determined empirically or by calculation, or by suitable formulae.

[0033]   For practical use, it is advantageous to learn a family of characteristics for the new state interval characteristic values of a storage battery in the new state, as a function of states of charge and battery temperatures.

[0034]   In order to determine the amount of charge which can be drawn from a storage battery during operation, a measurement coefficient J is then calculated from an interval characteristic value for a determined state of charge and a measured battery temperature, and from the learned new state interval characteristic value for the determined state of charge and the measured battery temperature. The amount of charge which can be drawn is then determined as a function of the measurement coefficient J, the state of charge, and the battery temperature. The interval characteristic values are thus evaluated with reference to new state interval characteristic values.

[0035]   The measurement coefficient J may, for example, be the difference between or the ratio of the interval characteristic value and the new state interval characteristic value.

[0036]   The method according to the invention makes it possible to determine the amount of charge Q_R which can be drawn from a storage battery by evaluation of the current and voltage profiles which can be measured during operation of the storage battery.

[0037]   For this purpose, the battery voltage $U(t)$ and the battery current $I(t)$ are measured with a suitable time resolution, preferably of less than 1 second (s), and the battery voltage values or profiles $U(t)$ and the battery current values or profiles $I(t)$ are smoothed, for example, using at least two low-pass filters with different time constants τ. The second time constant τ_2 should in this case be shorter than the third time constant τ_3. The smoothing can also be carried out by averaging, for example sliding averaging over different time windows, or the like. FIGURE 1 shows corresponding battery current profiles smoothed using different time constants τ.

[0038]   Voltage differences $\Delta U_{23}(t)$ are then calculated for one time interval in each case from the difference between the battery voltages $U(t)$ filtered using the second time constant τ_2 and the battery voltages $U(t)$ filtered using the third time constant τ_3. In the same way, the current differences $\Delta I_{23}(t)$ are calculated from the difference between the battery currents $I(t)$ filtered using the second time constant τ_2 and the battery currents $I(t)$ filtered using the third time constant τ_3.

[0039]   A characteristic value $K(t)$ is then calculated from the quotient of the voltage differences $\Delta U_{23}(t)$ and the current differences $\Delta I_{23}(t)$ as a function of the time, in each case limited to the time intervals Δt. An

interval characteristic value Km is calculated, preferably by averaging, from the characteristic values K(t) for in each case one time interval Δt, and the amount of charge Q_R which can be drawn is determined as a function of the interval characteristic value Km. This will be clearer from the following equations:

$$Q_R(\Delta t) = f(Km(\Delta t)) = f\left(\frac{1}{T} \int \frac{(U_{\tau 3}(t) - U_{\tau 2}(t))}{(I_{\tau 3}(t) - I_{\tau 2}(t))} dt\right)$$

[0040] The process of determining the amount of charge Q_R which can be drawn is in this case based only on permissible characteristic values K(t) which satisfy at least one of the following conditions: a) the magnitude of the current difference $\Delta I_{12}(t)$ between the battery current I(t) filtered using the second time constant τ_2 and the battery current I(t) filtered using a first time constant τ_1 is less than a defined first limit value I_{limit1}; b) the magnitude of the current difference $\Delta I_{23}(t)$ is less than a defined second limit value I_{limit2}; and c) the battery currents I(t) filtered using the second time constant τ_2 are greater than a defined third limit value I_{limit3} and less than a defined fourth limit value I_{limit4}.

[0041] Optionally, it is also possible to stipulate that the magnitude of the current difference $\Delta I_{23}(t)$ is greater than a defined fifth limit value I_{limit5}, and the magnitude of the current difference $\Delta I_{12}(t)$ is greater than a defined sixth   value I_{limit6}.

[0042] The conditions can be expressed by the following equation:

$$I_{limit\,5} < \left| I_{\tau 3}(t) - I_{\tau 2}(t) \right| < I_{limit\,2}$$

$$I_{limit\,6} < \left| I_{\tau 2}(t) - I_{\tau 1}(t) \right| < I_{limit\,2}$$

$$I_{limit\ 3} < I_{\tau 2}(t) < I_{limit\ 4}$$

For starter lead-acid rechargeable batteries with a size of 70 Ah, it has been found to be advantageous to use orders of magnitude for the first limit value of I_{limit1} = 1 A, for the second limit value of I_{limit2} = 1 A, for the third limit value of I_{limit3} = -5 A, and for the fourth limit value of I_{limit4} = -2 A. The current limit values themselves are dependent on both the battery size and its type.

[0043]   FIGURE 1 shows a diagram of battery current values I(t) smoothed using a first time constant τ_1, a second time constant τ_2, and a third time constant τ_3, plotted against time, with defined limit values I_{limit1}, I_{limit2}, I_{limit3} and I_{limit4}. As can be seen, the definition of the limit values means that the characteristic value K can be determined essentially only in the central and rear area of the first decaying flank of the current pulse, since this is the only place where the limit value conditions are satisfied.

[0044]   FIGURE 2 shows one possible flowchart for the method according to the invention for determining the amount of charge Q_R which can be drawn. In this case, the evaluation process is restricted to those times in which the battery is being discharged.

[0045]   This clearly shows that the battery currents I(t) are filtered using three low-pass filters with different time constants τ_1, τ_2, τ_3. A check is carried out to determine whether the filtered current value $I_{\tau 1}(t)$, $I_{\tau 2}(t)$, $I_{\tau 3}(t)$ satisfies the conditions described above, that is to say whether:

$$\left| I_{\tau 1} - I_{\tau 2} \right| < I_{limit\ 1}$$

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$$\left| \, I_{\tau 2} - I_{\tau 3} \, \right| < I_{\text{limit } 2}$$

$$I_{\text{limit } 3} < I_{\tau 2} < I_{\text{limit } 4}$$

$$I_{\tau 2} < 0$$

[0046] If this is the case, the damped current values I(t) and the voltage values $U_{\tau 2}(t)$ and $U_{\tau 3}(t)$ damped using a low-pass filter with a second time constant $\tau 2$ and a low-pass filter with a third time constant $\tau 3$ are used to calculate a characteristic value K(t) from the formula:

$$K(t) = \frac{\left(U_{\tau 3}(t) - U_{\tau 2}(t) \right)}{\left(I_{\tau 3}(t) - I_{\tau 2}(t) \right)}$$

[0047] An integrated characteristic value Ki

$$Ki = \int K \cdot dt$$

is determined, for example by integration, from the characteristic values K(t) for a time interval Δt, and the time duration T of the time interval are calculated by integration of the times in which the conditions are satisfied.

$$T = \int dt$$

[0048] The interval characteristic value

$$Km = \frac{Ki}{T}$$

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is then calculated as the mean value of the permissible characteristic values $K(t)$.

[0049]   The interval characteristic value Km is assessed at the end of a time interval Δt, preferably as a function of the state of charge SOC and of the battery temperature T_{Bat}, and the amount of charge Q_R which can be drawn is determined.

[0050]   The amount of charge Q_R which can be drawn can be determined with the aid of the predetermined families of characteristics, which are determined empirically or by calculation, as a function of the state of charge SOC and of the battery temperature T_{Bat}.

[0051]   If the relationship between the state of charge and the battery temperature T_{Bat} is known, it is also possible to correct the characteristic value $K(t)$ appropriately. It is also worthwhile weighting the characteristic value $K(t)$ as a function of the situation in which the storage battery is being operated. For example, time intervals Δt in which the storage battery is being charged can be weighted differently than time interval Δt in which the battery is being discharged.

[0052]   In order to make it possible to use the interval characteristic value Km to deduce the amount of charge Q_R which can be drawn, a new value interval characteristic value Km_{new} is preferably determined as a function of the states of charge SOC and battery temperatures T_{Bat}, and is defined as a characteristic value. This can be determined by learning a family of characteristics.

[0053]   A measurement coefficient J is then determined during operation from the difference between or the ratio of the interval characteristic value Km and the new value interval characteristic value Km_{new} for the respectively existing states of charge SOC and battery

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temperatures T_{Bat}. The new value interval characteristic values Km_{new} are thus compared with the determined interval characteristic values Km for the same state of charge SOC and battery temperature T_{Bat}. The amount of charge Q_R which can be drawn is then determined as a function of the state of charge SOC, of the battery temperature T_{Bat} and of the measurement coefficient J, for example with the aid of families of characteristics.

[0054]   FIGURE 3 shows a diagram of a starter battery with a size of 70 Ah to show the amount of charge Q_R which can be drawn, plotted against the characteristic value Km, as a function of the battery temperature T_{Bat} of 0° and 25°. The state of charge SOC is 70%.

[0055]   This clearly shows that there is a unique relationship between the amount of charge Q_R which can be drawn and the characteristic value Km, provided that the battery temperature T_{Bat} and the state of charge SOC are known. Corresponding families of characteristics can be determined for further states of charge SOC and battery temperatures T_{Bat}, and can be stored. This data can be then be used as the basis for using the interval characteristic values Km, which have been calculated using the method according to the invention as described above, to determine the amount of charge Q_R which can be drawn.

[0056]   It is important to note that the method as described in the preferred and other exemplary embodiments is illustrative only. Although only a few embodiments of the present inventions have been described in detail in this disclosure, those skilled in the art who review this disclosure will readily appreciate that many modifications are possible without materially departing from the novel teachings and advantages of the subject matter recited herein. Other substitutions, modifications, changes and omissions may be made in the design, operating conditions and

arrangement of the preferred and other exemplary embodiments without departing from the scope of the present inventions.